

Spraying device and method for fluidised bed granulation

The invention concerns a spraying device for use in high capacity fluid bed granulation and a method for preparation of solid granules from a liquid material in a fluid bed.

More specifically, this invention relates to spray nozzles usable for supplying granule-growth liquid, by atomising the liquid in a fluidised bed of solid particles where upon the microscopic liquid drops are sprayed.

The fluidised bed granulation process originally designed by Nederlandse Stikstof Maatschappijⁱ, later known as the NSM and now the HFT (Hydro Fertilizer Technology) granulator, has proved to have great advantages over other processes for granulating fertiliser substances like urea and ammonium nitrate, see for example US patent No. 5 653 781. The HFT granulation process combines very high capacity with excellent product properties and low energy consumption. In achieving this, the way of spraying the liquid to be granulated into the fluidised bed is of the highest importance. The design of the nozzles where the liquid is atomised influence the liquid flow capacity – and thus the capacity of the granulator – as well as the pressure and volume flow of atomisation gas required to maintain spouts with continuous and uniform sprays without agglomeration and unwanted disturbance of the fluidised bed. Finally the nozzle design also influences the energy consumption of the granulator through its flow and pressure characteristics.

State-of-the-art spraying devices (nozzles) are generally of the binary type atomising nozzles, where a gas, e.g. air, is used to atomise the liquid to be granulated. In principle the gas and liquid may be introduced through the nozzle in the same single tube, or gas and liquid may be introduced separately through for example concentric tubes so that the mixing takes place only in and after the nozzle aperture. The principle aims are effective gas-liquid mixing; uniform and small size of liquid particles and a suitable geometry of the resulting spray or spout, so that the atomised liquid (microscopic droplets) are continuously and homogeneously accreted on the granules formed in the fluidised bed.

Most nozzle designs available are not designed for use in high capacity granulation. Nozzles for granulation must be able to handle concentrated solutions (up to 99%) or melts without clogging or other problems ruining the production process. At the same time, there are notable differences between different designs with regard to energy

consumption of the process, capacity (product throughput) and quality of the formed granules. Existing and previous nozzle types need relatively high levels of atomisation gas, at elevated pressures, which again means high energy consumption.

5 Nozzles for use in a granulation process is for example described in US patent No. 4 701 353. These have a central channel through which the liquid material is supplied, and a channel concentric therewith carrying a powerful gas stream. The liquid is passed through a rotation chamber before it is mixed with the gas stream. The nozzle may also have a concentric outer channel for providing a less energy-rich gas stream. However, this nozzle
10 design has limitations in liquid flow capacity and in the energy required for both nebulising or atomising the liquid into suitable droplets and at the same time fluidising the droplets into a properly shaped spout where the particle growth will occur. The rotation chamber described by US 4701353 will only serve to give the liquid a helical movement, while the mixing chamber of the novel device described below will allow a thorough mixing of
15 atomising gas and liquid before the spray leaves the exit aperture of the nozzle. Thereby the kinetic energy from the gas and liquid is utilised optimally. The novel device and method described herein demonstrate high granulation capacity and low energy consumption; several times better than the values quoted in US patent No. 4 701 353.

20 In cases where a second concentric gas tube is fitted on the nozzle, like described in Claim 5 of US4701353, such design complicates the device unnecessarily compared to the device described below, since the novel device and method makes use of a portion of the fluidisation gas supply for the extra spout gas channelled up around the nozzle.

25 International patent application WO 02083320 also describes a nozzle for use in fluid bed granulators. It has a central supply for liquid where the liquid thereafter is led through a swirling device and into an internal mixing chamber. Gas is supplied to the mixing chamber through a plurality of openings in the wall in the lower part of the mixing chamber. However, the description reveals no examples and no figures relating to the practical applicability of the described design, whereas the novel device and method
30 described below has proved itself through high production capacity, good product quality properties and low energy consumption, in comparison with any other previously described designs.

35 The object of the invention is to obtain a granulation process with reduced energy consumption and enhanced granulation capacity; both factors reducing the variable costs of the granulation step. Another object is to obtain granules of better quality.

These objects of the invention are obtained with the device and method as described below, and the invention is further defined and characterized by the accompanying patent claims.

5 The invention thus concerns a spraying device for melt granulation in fluidised bed comprising a nozzle with a feed channel for a liquid to be atomised, where the liquid is led through emulsifying means and into an internal mixing chamber for gas and liquid, before it is fed to the fluidised bed. The nozzle has a separate channel for the atomising gas fitted concentrically around the central liquid supply channel for the liquid to be atomised
10 or nebulised. The mixing chamber surrounds the outlet zone of the liquid spray from the emulsifying means and the gas, allowing efficient mixing of high speed atomisation gas and liquid, and having an external gas cap where fluidisation gas is channelled into a spout above the spraying device. The mixing chamber could be cylindrical with an upper conical part or conical. The length/diameter ratio L/D of the mixing chamber should be
15 within the range 0.5 to 5 and the l/d ratios in the range 0.1 to 2. Preferably the ratio L/D of the mixing chamber is in the range 1 to 4 and the l/d ratios in the range 0.25 to 1.

The gas cap is conical and fitted to a perforated bottom plate, concentrically around the nozzle. The gas cap should have a height of 10 to 200 mm above the bottom plate (3),
20 preferably 20 to 100 mm. The upper aperture diameter of the gas cap is 20 to 150 mm and the bottom aperture diameter of 30 to 300 mm, preferably 35 to 100 mm and 40 to 200 mm, respectively.

The invention also concerns a method for preparation of solid granules in a fluidised bed,
25 where a liquid material is atomised by supply of an atomising gas and sprayed into the fluidised bed through spray nozzles mounted vertically and where the fluidised bed is maintained by fluidisation gas blown upwards through a perforated plate underneath the bed. A portion of the fluidisation gas should be channelled through a gas cap surrounding the nozzle for creation of a gas spout above the spraying device.

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The invention also concerns a method for preparation of solid granules from a liquid material in a fluidised bed by using a nozzle with a feed channel for a liquid to be atomised. The liquid is led through emulsifying means and into an internal mixing chamber for gas and liquid, before spraying the atomised liquid upwardly into the fluid bed
35 layer. The atomising gas is led through a channel concentrically to the liquid supply and into the mixing chamber surrounding the outlet openings for both liquid and gas, allowing efficient mixing of high speed atomisation gas and liquid. A portion of the fluidisation gas

is channelled through a gas cap surrounding the nozzle for creating a gas spout above the spraying device.

The spraying device could be used for production of granules of urea, and other fertiliser products, such as calcium ammonium nitrate, ammonium nitrate, ammonium sulphate and mixtures thereof.

The invention will be further explained with reference to the accompanying drawings, Figures 1-4, wherein

Figure 1 shows the principle difference between prior art design and the novel nozzle design.

Figure 2 shows design of gas cap and position of gas cap concentrically outside the nozzle.

Figure 3 shows nozzle design with cylindrical mixing chamber.

Figure 4 shows nozzle design with conical mixing chamber.

In a granulation process the liquid is sprayed into a fluidised bed through spray nozzles mounted vertically and spraying the atomised liquid upwardly into the fluid bed layer. The fluidised layer is maintained by fluidisation gas blown upwards through a perforated plate underneath the bed. The nozzles are placed in openings in this plate with their apertures a given distance. e.g. 5 – 100 mm, above the plate.

The design of the nozzles where the liquid is atomised influences the liquid flow capacity and thus the capacity of the granulator. It also influences the pressure and volume rate of atomisation gas required to maintain spouts with continuous and uniform sprays, without unwanted agglomeration and disturbance of the fluidised bed. Finally the nozzle design also influences the energy consumption of the granulator through its gas flow characteristics. This has a direct impact on the variable costs of the operation. The nozzle should atomise the liquid into droplets at desired size, approximately 50-100 micron for a single phase melt. At the same time the nozzle should evaporate some of the water, without creating premature solidification. It should also distribute and deliver droplets into the bed at the same time as it should contribute to movement around the nozzle and mass exchange in the bed.

The main novelty of the invention is the use of low energy fluidisation gas to replace a large portion of the high-pressure atomisation gas required. This is achieved by channelling the fluidisation gas through a specially designed gas cap surrounding the nozzle, thus creating a gas spout. A novel mixing chamber upstream from the nozzle aperture improves the internal mixing of gas and liquid in the atomisation process in the nozzle.

Splitting the gas in two tailored functions gives freedom to split the four key functions in atomisation and movement.

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Atomisation

- 1) The atomisation is done with minimum energy consumption, sufficient to create droplets and deliver them into the bed.
- 2) The desired evaporation rate can be tailored, according to the properties of the melt, being water content, heat of crystallisation, sub-cooling properties and crystallisation curve.

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Impact

- 3) The droplet transport and spout shape is tailored to the geometrical dimensions of the bed, where bed depth is a key.
- 4) The impact is also tailored to give mass transport of seed particles into the spout area.

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The present invention has effected that the granule quality characteristics and granulation capacity may be maintained or even improved, while energy consumption is considerably reduced, compared to those nozzles hitherto used in granulation. The reduced energy consumption is obtained because the atomisation gas can be operated at lower pressure, without increasing the total amount of fluidisation gas. This design still allows a high melt throughput and excellent physical characteristics of the granules.

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In Figure 1 the principle difference between prior art design and the novel design of this invention is shown. In prior art design (case I) mixing of liquid (L) and atomisation gas (G1) takes place in the fluid bed by the external impact of gas (G1) on the liquid (L). In the new nozzle design (case II) an internal mixing of gas (G2) and liquid (L) takes place in a mixing chamber. At the same time a part of the atomisation gas is replaced by fluidisation gas (G3) led into a spout in the fluid bed by the novel gas cap mounted concentrically outside the nozzle. Part of the atomisation gas is thus replaced by fluidisation gas (G3) supplied via the gas cap. The required amount of atomisation gas has been reduced

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drastically compared with the known nozzle designs, as will be illustrated by the examples (from 80-250 kg/h to 32 kg/h).

In Figure 2 A the design of the gas cap and position of gas cap concentrically outside the nozzle is shown. Figure 2B shows a horizontal section along A-A. The conically shaped gas cap 1 is mounted concentrically around the nozzle 2 on a perforated sieve plate 3 and exposed to fluidisation gas. The top diameter of the gas cap device is smaller than the bottom diameter, and there is clearance for gas passage between the outer nozzle wall and the gas cap. The amount of gas through the gas cap shall be sufficient to create a viable spout into the granulator bed. The velocity of gas through the gas cap is determined by the horizontal area between nozzle and gas cap, the upper diameter of the gas cap aperture and the diameter of the bottom inlet of the gas cap. The mass flow of fluidisation gas per square meter horizontal bed area remains almost unchanged from the known designs.

Figure 3 shows the new nozzle design with cylindrical mixing chamber. The ratio length: diameter (L/D) of the mixing chamber could be varied as indicated in the drawing. Omitted from the figure are feed lines, the perforated bottom plate of the granulator and the conical cap mounted concentrically to the nozzle on the bottom plate. The nozzle 2 is composed of a central channel 4 which at one end A connects with a liquid line omitted from the drawing and at the other end leads B into a mixing chamber 5. In a position between openings A and B a swirling device 6 is mounted inside to bring the feed via A in helical motion at point B. Further, the spraying device is provided with a channel 7 which has been fitted concentrically around the central liquid supplying channel 4. Channel 7 being at one end connected to a gas line omitted from the drawing and at the other end provided with 5-15 round holes 8, which leads into the mixing chamber 5. The two continuous flows are fed inside the mixing chamber at the same time: a granule's growth liquid through opening B and a gas flow via 8. In this mixing chamber a gas in liquid emulsion can be generated. Expansion through the orifice opening 9 converts the emulsion to droplets of 50 – 100 μm diameter, which are suitable for granule growth in the fluidised bed.

Figure 4 shows a nozzle with a conical mixing chamber 5. The other parts of the nozzle are the same as in Figure 3.

From literature (Lefebvre A.H.: Atomization and sprays, Taylor & Francis, 1989, p-214-215 and p-232, (ISBN:0-89116-603-3), it seems that the l/d (length/ diameter) of the orifice and the ratio of the L/D (length/ diameter) of a mixing chamber are important factors for the

formation of the liquid droplets. Based on these assumptions and our own findings the L/D ratio should be in the range 0.5 to 5, and the l/d ratio in the range 0.1 to 2 in order to efficiently obtain droplets with average diameter less than 100 μm . Preferably L/D should range from 1 to 4 and l/d from 0.25 to 1.

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Energy efficiency has also been calculated for the new design nozzles. Standard and common equations are used, see Perry's Chemical Engineers' Handbook (chapter thermodynamics).

10 $W = \Phi_M * C_p * \Delta T$ [kJ/s]
 $\Delta T = T_2 - T_1$ and $T_2 = T_1 * (p_2/p_1)^{(k-1/k)}$ [K]
 Φ_M = mass flow of melt
 C_p = specific heat of gas [kJ/K kg]
 T_1 = ambient temperature
 15 T_2 = temperature after fan
 p_1 = gas pressure before fan
 p_2 = gas pressure after fan
 k = gas constant

20 For the calculations the following assumptions were made:
 Adiabatic conditions
 Ambient air temperature : 25 °C
 Pressure loss : 5000 Pa
 Fan efficiency : 0.80

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According to the calculations it is possible to reduce the energy consumption of the fluidisation and atomisation air supply by about 50 %. The energy reduction that actually is achieved using the novel spraying device is shown in Example 1 below.

30 The parameters moisture content, density and crushing strength of urea granules produced with the novel nozzle design have comparable or better values compared to granules produced with existing designs. This is illustrated in examples below.

It has experimentally been found that when using an internal gas/liquid mixing chamber
 35 nozzle instead of an external gas/liquid-mixing nozzle, it is possible to make granules with better chemical and physical properties, with less energy consumption

In granulation units, especially for urea and ammonium nitrate, it has also been an important aim to reach high production capacities, avoiding the need to have more than one single granulation unit per synthesis unit, while minimising variable costs.

- 5 The invention will be further illustrated by the following examples describing granulation of urea. The examples will demonstrate values obtained for product quality parameters as well as energy consumptions for a range of nozzles based on the novel design.

The examples were carried out under the conditions given below:

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A granulator was fit with the experimental nozzle in the centre. The conical gas cap had a lower diameter of 105 mm and an upper diameter of 50 mm. It was mounted on a 4.5% opening perforated sieve plate containing holes of 2 mm in diameter. The amount of air through this gas cap was 248 Nm³/h under a feed pressure equal to the fluidisation gas (air) pressure of about 800 mmwc and with a temperature of 40 °C. The granulations were carried out under normal standard urea granulation conditions with a melt of 96% urea containing 0.55 wt.% formaldehyde, with a temperature of about 132 °C. The set-up was supplied with fluidisation gas necessary to keep the bed in movement and also for creating a spout via the gas cap 'spout opening'. The atomisation gas with a flow rate of 32 kg/h and a temperature of 142 °C was supplied together with the melt into the nozzle's mixing chamber.

Product quality parameters such as moisture content, density, crushing strength of the granules with diameter 2.5-4.5 mm were analysed for each nozzle test. During the test different liquid flows have been used; 250, 350 and 450 l/h. Each granulation test was at least carried out in duplicate.

It is also possible to produce nitrate products with 33.5% N and 27% N with this kind of nozzle.

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Example 1 -Nozzle with cylindrical mixing chamber L/D=2.75

In this example it has been used a spraying device of type H5 as shown in Figure 3, with L/D ratio 2.75 of the mixing chamber. The results are compared with experiments carried out in nozzles of prior art design.

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Table 1. Operating parameters

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Nozzle		HFT design (prior art)		Novel design L/D=2.75	
		Ex. A	Ex. B	Ex. A	Ex. B
Urea feed flow	kg/h	540	450	540	454
Urea feed pressure	bar	1.4	1.3	2.1	1.8
Fluidisation gas (air) flow	kg/m ² .h	7952	7952	8107	8107
Fluid. gas (air) pressure	mmwc bar	800 0.08	800 0.08	800 0.08	800 0.08
Spout. gas (air) flow	kg/h	-	-	320	320
Atom. gas (air) flow	Nm ³ /h	252	252	32	32
Atom. gas (air) pressure	bar	0.5	0.5	1.9	1.5

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Table 2. Obtained product properties, urea

Nozzle		HFT design (prior art)		Novel design L/D =2.75	
		Ex. A	Ex. B	Ex. A	Ex. B
Moisture	%	0.26	0.23	0.20	0.19
Density	kg/l	1.216	1.23	1.237	1.25
Crushing strength	kg	4.40	4.44	4.95	5.03
Abrasion	mg/kg	800	650	175	195

Table 3. Power consumption

Nozzle	HFT design (prior art)	Novel design L/D =2.75
	Experiment A	
Power consumption (W_T) (kWh per tonne product)	27	13

The power consumption is calculated as described in the description. Air is used as fluidisation and atomisation gas, hence the $k = 1.40$ and $C_p = 1.04$ corrected for humidity of the air.

Example 2 –Nozzle with cylindrical mixing chamber L/D=1

The working principle and design is with exception of the mixing chamber length the same as described in example 1. In this design the length of the mixing chamber is 20 mm instead of 55 mm so that the L/D ratio changed from 2.75 to 1. The results are compared with experiments carried out in nozzles of prior art design.

Table 4. Operating parameters

Nozzle		HFT design (prior art)		Novel design L/D=1
		Ex. A	Ex.B	
Urea feed flow	kg/h	540	450	450
Urea feed pressure	bar	1.4	1.3	1.8
Fluid. gas (air) flow	kg/m ² .h	7952	7952	8107
Fluid. gas (air) pressure	mmwc	800	800	800
	bar	0.08	0.08	0.08
Spout. gas (air) flow	kg/h	-	-	320
Atom. gas (air) flow	kg/h	252	252	32
Atom. gas (air) pressure	bar	0.5	0.5	1.5

Table 5. Obtained product properties, urea

	Nozzle:	HFT design (prior art)		Novel design L/D=1
		Ex. A	Ex. B	
Moisture	%	0.26	0.23	0.18
Density	kg/l	1.216	1.23	1.24
Crushing strength	kg	4.40	4.44	4.75
Abrasion	mg/kg	800	650	140

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Example 3 –Nozzle with conical mixing chamber

- 10 In this example it has been used a spraying device with conical mixing chamber as shown in Figure 4. The L/D ratio of the nozzle was 2.75. The results are compared with experiments carried out with nozzles of prior art design.

15 This mixing chamber nozzle with conical shape has also 12 inlet gas openings (D), which are placed, in an angle directed towards the rotational direction of the liquid swirl. It is constructed to give the atomisation gas a rotation in opposite direction to the liquid, in order to make a maximum impact of gas into the liquid flow.

Table 6. Operating parameters

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	Nozzle :	HFT design (prior art)		Novel design Conical
		Ex. A	Ex. B	
Urea feed flow	kg/h	540	450	375
Urea feed pressure	bar	1.4	1.4	1.9
Fluid. gas (air) flow	kg/m ² .h	7952	7952	8107
Fluid. gas (air) pressure	mmwc	800	800	800
	bar	0.08	0.08	0.08
Spout. gas (air) flow	kg/h	-	-	320
Atom. gas (air) flow	kg/h	252	252	32
Atom. gas (air) pressure	bar	0.5	0.5	1.7

Table 7. Obtained product properties, urea

		HFT design (prior art)		Novel design Conical
		Ex. A	Ex. B	
Moisture	%	0.26	0.23	0.21
Density	kg/l	1.216	1.23	1.20
Crushing strength	kg	4.40	4.44	4.51
Abrasion	mg/kg	800	650	1430

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By use of the new nozzle design in a granulation process it is possible to produce granules at a lower energy consumption, with better quality and at an increased capacity.